COLLIMATOR DESIGN FOR THE HEBT LINE OF THE SNS PROJECT*

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Abstract

This paper summarizes the design of the HEBT clean-up system consisting of a combination of charge exchange foils and absorbers. Pairs of foils moving in-and-out of the beam in both planes help guide the halo protons into respective absorbers that feature a double wall beam-tube, a water-cooled particle bed responsible and heavy radial shielding. Off-momentum protons are directed to a momentum dump via similar charge exchange foils and in combination with a dipole magnet. The paper addresses the survivability of the double beam tube in the absorber and the special window in the momentum dump that intercept halo protons over a relatively small footprint under normal operating conditions and potentially full beam under accident conditions.

1. INTRODUCTION

The collimator absorber array of the Spallation Neutron Source (SNS) project is responsible for stopping the 1.0 GeV protons that are in the halo of the beam. It is estimated that 0.1% of the 2 MW beam will be intercepted by the adopted collimating scheme implemented at various sections of the beam transport and accumulation. The design of the HEBT clean-up system is a combination of charge exchange foils and absorbers. Figure 1 depicts the layout of the HEBT line where collimation is taking place.

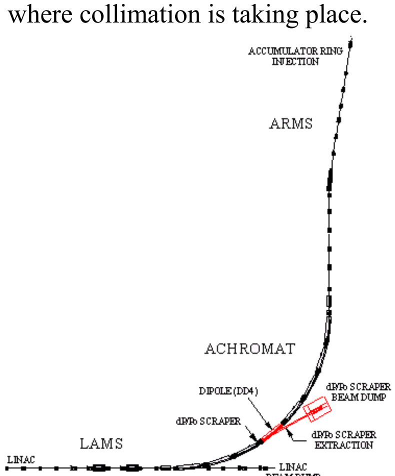

Figure 1: SNS HEBT line layout

Figure 2 shows the collimator acceptance in terms of betatron amplitude and δp/Po.

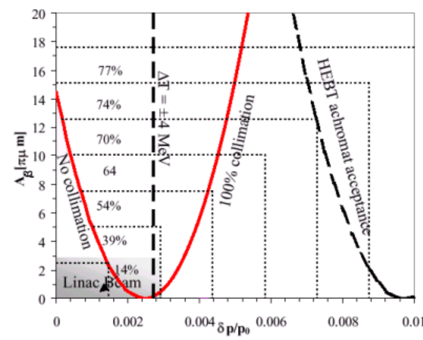

Figure 2: Collimator acceptance

The actual collimating scheme consists of two pairs of foils moving in-and-out of the beam in the vertical and horizontal directions that help guide the halo protons into respective absorbers. The two longitudinal absorbers consist of an intricate design of a double wall beam tube, a water-cooled particle bed responsible for stopping the incoming protons, and heavy radial shielding surrounding the particle bed. The off-momentum protons are directed to a momentum dump with the help of respective charge exchange foils and a dipole magnet. Figure 3 depicts the charge exchange process. Shown are the two distinct tails of halo protons that are directed into the dump. The momentum dump consists of a cooled particle bed and is surrounded by shielding. It interfaces with a double wall window separating the vacuum space from the rest of the dump. Its special design that allows for the removal of deposited energy from both window walls.

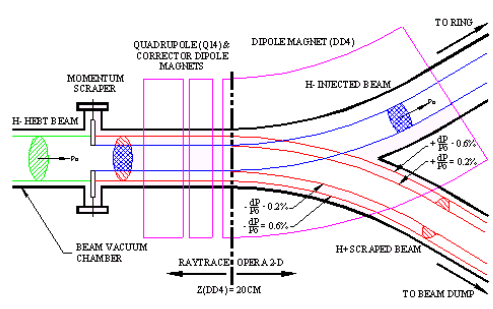

Figure 3: Charge exchange foil schematic

* This work was performed under the auspices of the US DOE

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The survivability of the double beam tube intercepting halo protons over a relatively small footprint under normal operating conditions and potentially the full beam under accident conditions is of primary concern. Under similar conditions the momentum dump widow, which intercepts off momentum protons over two tight spots and potentially the full beam in an accident scenario was evaluated. For both critical systems special attention was paid in the material selection. Thermo-mechanical considerations and irradiation data availability led to the selection of Inconel-718 as the material of choice. Figure 4 depicts the HEBT proton beam structure. It is postulated that in the event of an accident, during which more beam than anticipated is lost during charge exchange, the accelerator will be tripped after two (2) 900ns period pulses. That will significantly limit the failure potential in the collimating components that intercept the beam.

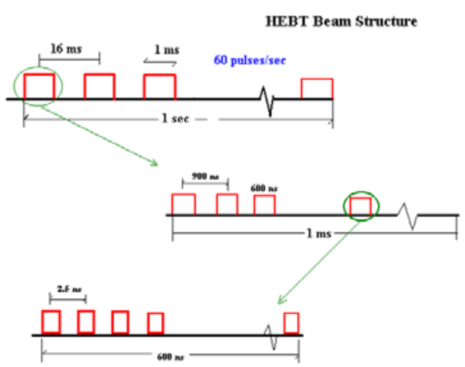

Figure 4: HEBT beam structure

2. COLLIMATOR DESIGN

2.1 HEBT Collimator

Following the conceptual design of the collimator absorber, thermal and stress analysis of the key elements guided its final absorber configuration. Figure 5 depicts the final design configuration. The various analyses were aided by energy deposition calculations performed by the neutronic codes and MCNPX [5] under both normal and off-normal conditions.

As mentioned previously, given the location and the function of the beam tube within the collimating assembly, a material that exhibits good mechanical strength properties and has good resistance to radiation damage must be selected. The requirements become more stringent due to the fact that there is to be coolant (light water) on the back face of the beam tube. Inconel-718 possesses both the required strength and radiation resistance that is supported by experience data. The result of all requirements was a double Inconel-718 wall separated by a gap filled with pressurized helium. The purpose of the helium is twofold. On one hand it provides a heat transfer path to the outer wall and on the other it can be detected in the beam tube vacuum space if a leak in the inner wall occurs. The double wall concept also allows for the separation of the critical inner wall from the light cooling water. In order to help the heat transfer path from the inner wall to the flowing coolant, a cooper wire is introduced within the helium gap as shown in the detail of Figure 5. It is important to note that a very narrow cooling path has been introduced in the front transition section to help increase the heat transfer capacity of the system around this critical location. Shown in Figure 6 is the distinct "painting" of halo protons on the transition section of the absorber beam tube. Thermal calculations revealed that the section shown in the detail of Figure 5 is the one most severely heated and it required the higher thermal heat transfer capacity. A coolant flow of 5 gal/min is required in order for temperatures to remain low.

Under an accident condition, which consists of two 600ns pulses, the generated thermal stresses are quite small and pose no concern of failure in the double Inconel –718 wall.

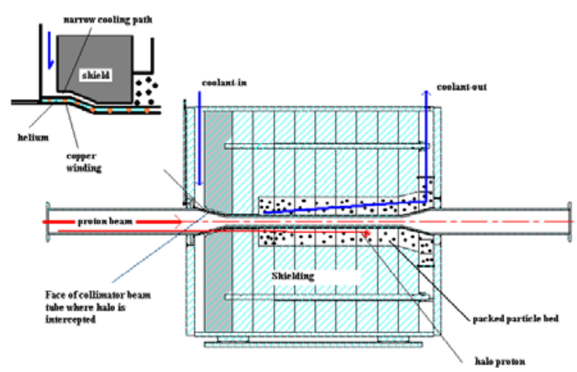

Figure 5: HEBT absorber configuration

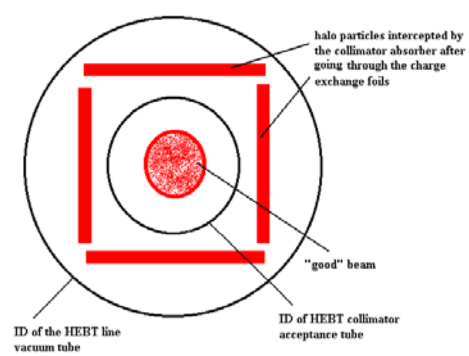

Figure 6: Halo particle "painting" on collimator wall

2.2 Momentum Dump

Depicted in Figure 3 is the extraction of the two distinct tails of momentum particles that are guided by the dipole magnet shown in Figure 7 onto the momentum dump. These extracted halo protons (H+) go through the double window structure, shown in Figure 8, and they stop within the volume of the particle bed. The cooling scheme allows for coolant to be rushed by the back face of the dump window and it enters the particle bed at the bottom through holes in the separator plate.

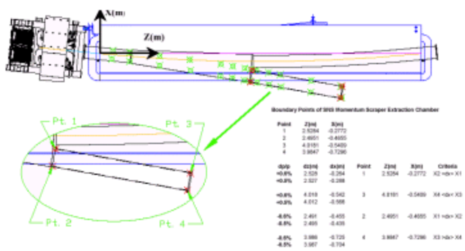

Figure 7: Momentum halo proton extraction

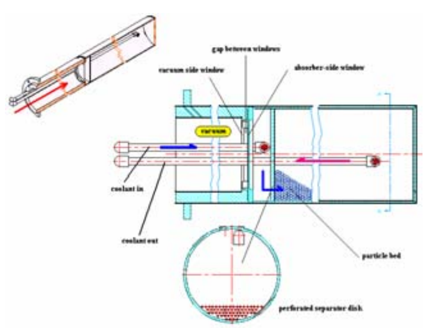

Figure 8: Design layout of the momentum dump

The low-pressure (receiving) point is chosen such that the coolant traverses the particle bed. The vacuum window has been designed to be cooled by radiation only. For conservative reasons the conduction path at the edge of the window flange has been ignored. Under steady state conditions heat will be transferred by radiation from the vacuum window to the dump window and removed by the flowing coolant that wets the back surface of the dump window. By introducing factors of safety of 5 in the energy deposition calculations, the maximum temperature increase in the vacuum window will be approximately 94 degrees C. The temperature distribution is shown in Figure 9. Figure 10 depicts the temperature change during two full beam pulses of an accident condition. The increase is over a small spot where the focused full beam is intercepted. Since there is a microstructure within each of the two pulses, the generated thermo-elastic stresses are incrementally small and are able to attenuate posing no threat to the integrity of the window.

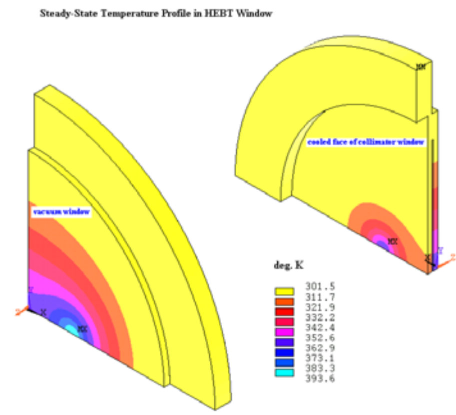

Figure 9: Thermal response in the momentum dump double window under steady-state conditions

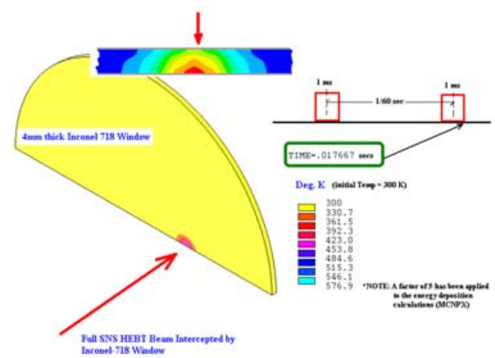

Figure 10: Thermal response of the vacuum window in the momentum dump under accident conditions

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